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Research Article

Supplier selection in supply chain network using MCDM methods

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ABSTRACT

Supply Chain Management (SCM) is an important factor for the success of companies, and competitive advantages provided by SCM methods are essential for sustainability in today's conditions. Under these circumstances, companies must successfully adapt to technology, customer expectations, and supplier management requirements to move ahead of other competitors. One of the important and strategic steps for supply chain management is the supplier evaluation and selection process. In this process, companies prefer multi criteria decision making methods rather than traditional methods because of the large number of supplier alternatives and the variety of evaluation criteria. Considering the aforementioned economic and competitive conditions, a supplier evaluation and selection method has been developed for a company which is operating in defense industry by using multi-criteria decision making methods. In accordance with the purpose of building an effective and sustainable system, Analytical Hierarchy Process (AHP) method has been implemented for the prioritization of the determined supplier evaluation criteria. TOPSIS method has been used to make an ideal selection and to rank among the alternative suppliers by using criterion prioritization determined by AHP method. In order to ensure the continuity of using these methods in the company, an Excel based software written with VBA programming language has been developed. The upgradeable data structure of this program aims to create a fast and effective decision making process under changing conditions. The feature that makes this study unique from other studies in the literature is that, as a result of the analysis performed with data specific to the defense industry sector, the ideal supplier rankings for six different business types are determined and also the created software is used for keeping preferred methods available any time in order to support decision makers in the selection processes of suppliers.

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INTRODUCTION

In today's world, with the effect of globalization, the concept of competition has become one of the most important factors in the strategic plans of companies. That's the reason why the need for companies to establish an efficient and an effective supply chain network has emerged in order for companies to have a healthy and a sustainable structure. It can be ensured that the service to be provided is accurate, timely, quality and cost effective with a correct supply chain structure. Supply Chain Management (SCM) offers important advantages for the concept of data and resource management as well as product management and human engineering, companies aim to become more competitive by using these advantages [1].

As the SCM becomes widespread and advantageous in terms of cost, instead of producing with their own resources, companies try to meet the needs with the services to be taken from outside [2]. Companies gain advantages in terms of delivery time and cost with this method; the most important condition for achieving these advantages and being sustainable on companies' well-selection to work within the supply chain. In recent years, the problem of accurate evaluation and selection of suppliers to be worked with comes to the fore as the reason for many scientific studies for the concept of outsourcing [3]. The most important issue in the establishment, sustainability and efficiency of the supply chain structure is to choose the right supplier and establishing long-term partnerships [4]. Evaluation criteria should be determined effectively in order to choose the right supplier. When determining these criteria, the criteria should be set according to the win-win partnership model [5].

Supply chain management and supplier relations have an important place in the Defense Industry sector as in other sectors. The most basic features that distinguish the Defense Industry sector in supplier selection and management are; working together with suppliers towards strategic goals, quality and safety standards that candidate companies should have, and the need to adapt to changing conditions dynamically. For this reason, it is important to make supplier selection practices more sensitive and take more criteria into consideration. With aresearch conducted in Germany; it has been emphasized that with the effect of supply chain management activities that have developed within the framework of features specific to the defense industry sector after 2000s, globalization, cost advantage and production efficiency in the sector have increased [6].

Under the aforementioned conditions, when methods for determining right and effective suppliers are examined, MCDM methods come to the fore. For many years, MCDM methods have been used in the military and defense industry sector for strategy determination [7], location selection, increasing of equipment efficiency, cost reduction [8] and many similar issues. In accordance with the information, with the creation a holistic model, it is aimed to have a dynamic structure that can allow calculations with up-to-date data in the study we conducted with the aim of meeting the needs of the sector in supplier evaluation and selection processes by using MCDM methods.

In the study presented, the subject has been examined in three main categories in order to select an efficient supplier in supply chain networks:

- Comparison matrix approach of AHP method was used to determine importance of the selection criteria used to analyze the suppliers. In these analyzes, 6 business types and 18 criteria that could provide values with data and heuristic methods were identified and a wide framework was tried to be drawn.
- TOPSIS method, which is frequently used in literature research, was applied to analyze the suppliers in the portfolio.
- A software was written with VBA programming language and made available to decision makers to create a fast and effective decision making process under changing conditions.
- It is aimed to provide the following contributions to the literature with this study;
- Presenting a unique structure for supplier evaluation and selection activities with the criteria which are specified for defense industry.
- Establishing structure for efficient and fast implementation of supplier evaluation and selection activities to adapt to changing conditions within the framework of sustainable methods.
- Developing a software to support decision makers.

The remainder of the paper is organized as follows: firstly, literature review is presented. Methodology used in our study is given in the third section. In the fourth section, determination of the supplier selection criteria and ranking of the alternative suppliers are explained. In the last section, the results of our study and suggestions for researchers are presented.

LITERATURE REVIEW

When the ratio of purchase values for a product to the sale price of the product is analyzed, this ratio is between 25% and 80% according to the sector and companies' outsourcing decisions [9]. This ratio is the largest value that directly affects the cost of a product. As a result of the aggravation of competitive conditions in the globalizing world, the fact that the aforementioned purchasing cost has a great impact on total cost, supplier selection, evaluation, and development processes has been one of the most important strategic issues of companies [10]. When the last 10 years are analyzed, it is observed that supplier performances have a great effect on the success and failures of the companies. For this reason, companies try to choose the suppliers that will generate win and win situation for both

the supplier and the customer, and establish long-term strategic relationships [11].

Chai et al., systematically examined the studies on supply selection for the last 5 years before 2013 and classified the decision making methods [12]. The prominent methods according to the outcomes of this study are multi-criteria decision making (MCDM) models, mathematical programming and artificial intelligence techniques. AHP, TOPSIS and ANP are the most frequently used methods among MCDM techniques; Linear programming, multi objective programming, and data envelopment analysis are found to be the most used among mathematical programming techniques. In our study, supplier evaluation and selection application will be realized by integrating AHP and TOPSIS methods. For this reason, AHP and TOPSIS, which are among the MCDM methods, were examined in the literature review section.

More than two hundred papers have been examined for the literature research, 65 of them have been obtained after the elimination based on their relation and compatibility to our topic the distribution of the articles examined by years is given below in detail (Figure 1).

In the literature review of similar studies at the Defense Industry sector, it is seen that the integration of AHP-TOPSIS methods used in the studies or their fuzzy versions are used in different problems and purposes. In the paper "Supplier Selection with Multi Criteria Decision Making Methods for Strategic Products in Defense Industry" written by Yunus Aydin and Tamer Eren, they tried to find solutions in supplier selection using AHP and TOPSIS methods [13]. Aydin and Eren aimed to select the supplier for strategic products in defense industry with MCDM methods, they used AHP and TOPSIS methods [13]. Similarly, other authors tried to find a solution in supplier selection by using the fuzzy version of TOPSIS method in the studies. Demirtas and Akdogan tried to select the supplier under fuzzy environment and proposed an application for defense industry [14]. Celikkol examined in detail nine of the MCDM methods for the defense industry in his supplier selection study and proposed an application based on TOPSIS for defense sector [15]. The main feature that makes the study described in the paper unique compared to similar studies examined in the literature is given below;

- The establishment of a sustainable mathematical and systematic structure that can be used continuously.
- The study can be used under different constraints.
- The aim is not reaching a single result or set of results, it is to support decision makers whenever needed.
- The study presents a unique structure in supplier evaluation and selection activities with evaluation criteria determined specifically for Turkish defense industry conditions.
- The study creates different perspectives by using MCDM methods in supplier evaluation and selection activities with the usage of the developing software in order to support decision makers.

AHP is one of the MCDM methods put forward by Saaty in 1980. AHP is based on a one-to-one comparison method with a predefined comparison scale on a hierarchy, both in terms of the criteria that influence the decision and the significance values of the decision points of these criteria. Although AHP method is used effectively in many decision making problems, it is criticized for using certain numbers when comparing criteria with each other [16]. In the paper, the AHP method was selected among other MCDM techniques for reasons given below;

- It is a robust, coherent and flexible decision making technique which dealing with complex problems in order to reach optimal decisions.
- Easy usability.
- AHP's dual comparison matrices method is the best fit for the study.
- Users do not require authentic and complex information sets.
- Ensuring efficiency in the evaluation of a large number of criteria.
- Flexibility to add new criteria if needed,
- Providing a decision mechanism that everyone will have an influence on when decisions are made in a group.
- Agility to achieve results.

Developed by Chen and Hwang in 1992, with reference to the work of Hwang and Yoon (1981), TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution) is a MCDM method used for sorting alternatives [17]. TOPSIS is very common in the selection of ideal solution between alternatives, the main reason of that it is easy in terms of application and interpretation. TOPSIS is based on the principle of proximity to the ideal solution. The method is based on the alternative options and criteria being close to the positive ideal solution and the maximum distance to the negative ideal solution [18]. The ideal solution is based on the principle of maximizing utility, minimizing cost. In

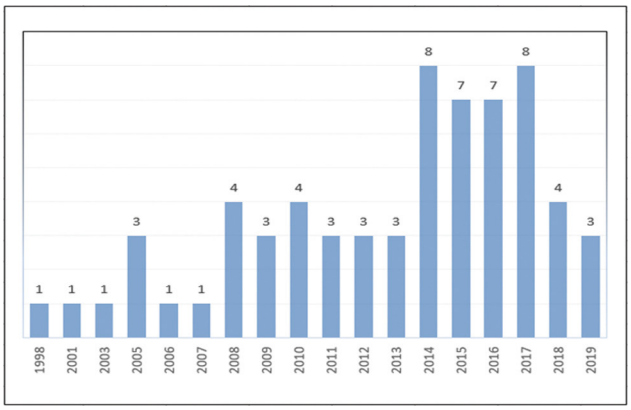

Figure 1. Distribution of the Papers Examined in our Research by Years.

the paper, the TOPSIS method was selected among other MCDM techniques for; its simplicity, good fit with AHP and the study, rationality, efficiency, intelligibility and it presents a global methodology and a simplified model for ranking and choosing suppliers in order to find optimal solution.

In the reviewed literature, similar and different criteria have been used according to the problem solutions that were previously made for different type of business and purposes, according to the type of purpose and geographical conditions. In Table 1, in which studies the criteria we use for our current paper are used in common are given in detail.

When Table 1 is examined in detail, it is observed that criteria of pricing, delivery performance and quality performance are used at 90% of observed papers and criteria of Customer Portfolio, Corporate Memory, Adaptation to Systems and Investment Potential used in our study were not used in previous studies. In our study, unlike the reviewed literature, six different business types were applied and a special software was developed to provide a quick support to decision makers by using the criteria determined for those business types.

Many authors used AHP, TOPSIS or combination of AHP-TOPSIS as MCDM methods in order to deal with decision making problems such as Deveci et al. [52] investigated a problem of a corridor selection for locating autonomous vehicles using the interval-valued intuitionistic fuzzy AHP and TOPSIS method and Gokasar and Deveci et al. [53] investigated CO2 Emission based prioritization of bridge maintenance projects with MCDM methods.

Also in the study, it is aimed to develop a decision support system in addition to the use of MCDM methods. Although there is no similar study has been carried out in the defense industry in Turkey, as a similar study within the scope of supply chain management activities, the article published by Teniwut and Hasyim [54] was reviewed which mentions about decision support systems in supply chain. In the article; sectoral, methodical and activity-based detailed analyzes regarding decision support systems were made. Also, Kusakci's [55] and Burney's [56] articles were analyzed which are about decision support systems by using hybridized fuzzy AHP TOPSIS methods.

METHODOLOGY

In this study, supplier evaluation and selection application was performed for a company operating at defense industry sector. The steps followed for the proposed study are given below (Figure 2);

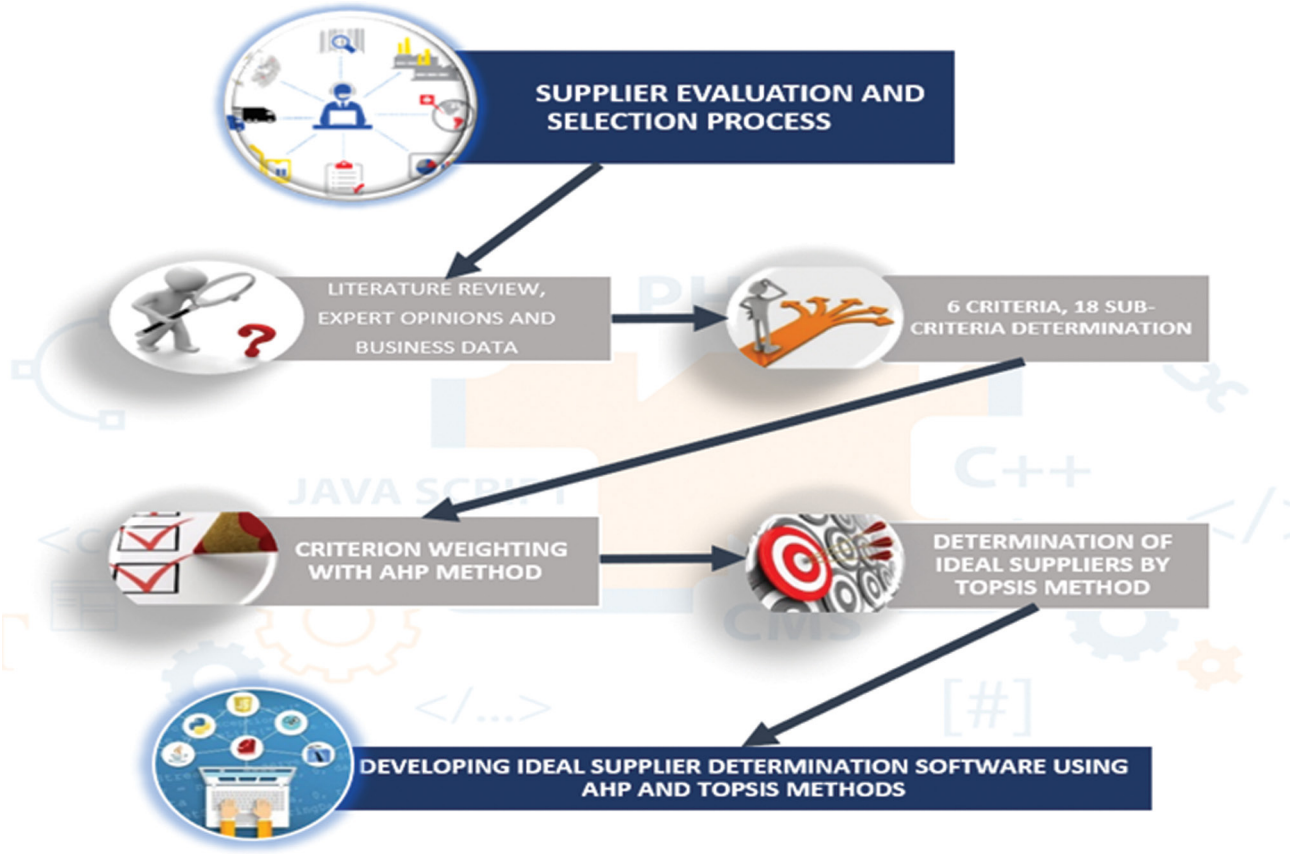

Figure 2. Steps of the Proposed Study.

Table 1. Criteria Analysis Used in the Literature

STUDY	PRICING	PERFORMANCEİ	COST OF PERFORMANCE	DELIVERY PERFORMANCE	QUALITY QUALIFICATION	TECHNICAL ALIGNMENT	STRATEGIC COMMUNICATION	LOGISTICS	QUALIFICATION	ORGANISATIONAL SYSTEMS	ADAPTATION TO EDUCATION	INVESTMENT POTENTIAL	CORPORATE MEMORY	QUALIFICATION	FINANCIAL INNOVATION	HUMAN RESOURCES	FLEXIBILITY	CUSTOMER PORTFOLIO
The Proposed Model	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
[16]	X		X	X	X													
[19]			X	X	X	X		X	X					X		X		
[20]	X		X	X				X										
[21]	X		X	X										X				
[22]	X		X	X		X												
[23]	X		X	X	X			X										
[24]	X		X	X					X						X			
[25]	X		X	X		X	X											
[26]	X		X	X		X												
[27]	X		X	X										X				
[28]	X		X	X		X												
[29]				X					X		X			X				
[30]	X	X					X											
[31]	X		X	X		X	X	X						X				
[32]	X		X	X			X										X	
[33]			X	X											X			
[34]	X		X	X														
[35]	X		X	X	X				X					X				
[36]	X		X	X		X												
[37]	X			X		X												
[38]	X		X														X	
[39]			X	X			X							X				
[40]	X		X	X														
[41]	X			X		X												
[42]	X		X	X	X	X	X										X	
[43]	X		X	X			X											
[44]	X		X	X	X		X		X									
[45]	X		X	X		X												
[46]	X		X	X	X		X	X						X			X	
[47]	X		X	X	X		X								X		X	
[48]	X						X	X										
[49]	X		X	X														
[50]	X		X	X														
[51]	X		X	X			X											

- Determination of supplier selection and evaluation criteria for the company where the application is carried out; While determining these criteria, studies in the literature were examined and opinions of experts working within the company were taken. Accordingly, 6 criteria and 18 sub-criteria were determined.

- Calculation of criteria weights using AHP method for the determined evaluation criteria.
- Ranking of alternative suppliers as a result of TOPSIS method with the participation of criteria weights determined with AHP method.
- Developing an excel VBA based software that can produce fast solutions to support decision makers.

Readers can find the detailed information about AHP method in the studies written by Saaty in 1990 and 2008[57, 58]. Also, for the detailed examination of TOPSIS method, they can also examine the study written by Hwang and Friends in 1993[59].

DEVELOPMENT OF SUPPLIER EVALUATION AND SELECTION SOFTWARE

With the aim to support decision makers, a software that achieved quick results was developed by using the methods described in the methodology section. In the development of the software, an Excel based structure was created using the VBA programming language. There are two basic steps in our software; the first one is to update the data used in AHP and TOPSIS methods, the second is the process of finding ideal suppliers according to the specified business types.

The software is able to adapt to dynamic conditions with its updatable data structure and can sort the ideal companies for different business types. On the supplier selection information screen, which is shown in the figure 3, when we press the "OK" button by selecting the candidate suppliers, it will be run according to the selected constraints.

The software is based on proposing the most ideal three companies by working under specified constraints. With the result screen given in figure 4, information is presented to the decision maker, and it is also possible to add notes and save the decision as a word document.

A CASE STUDY AT THE DEFENSE INDUSTRY

In this section; The process of determining the criteria to be used in the supplier selection processes of the company operating in the Defense Industry sector, the analysis of the criteria determined using the AHP method, the process of finding the most suitable alternative solutions among the determined types of business and suppliers with TOPSIS method and the analysis of the results were evaluated.

DETERMINATION OF CRITERIA

While determining the supplier selection and evaluation criteria for the company, the studies in the literature were examined and the opinions of the experts working within the company were taken by interviewing one by one, small group meetings and a full attended meeting. These experts consist of three managers (a mechanical engineer, two industrial engineers) with ten years or more experience in the sector and seventeen engineers (2 mechanicals, 1 material and 14 industrial engineers) working directly in

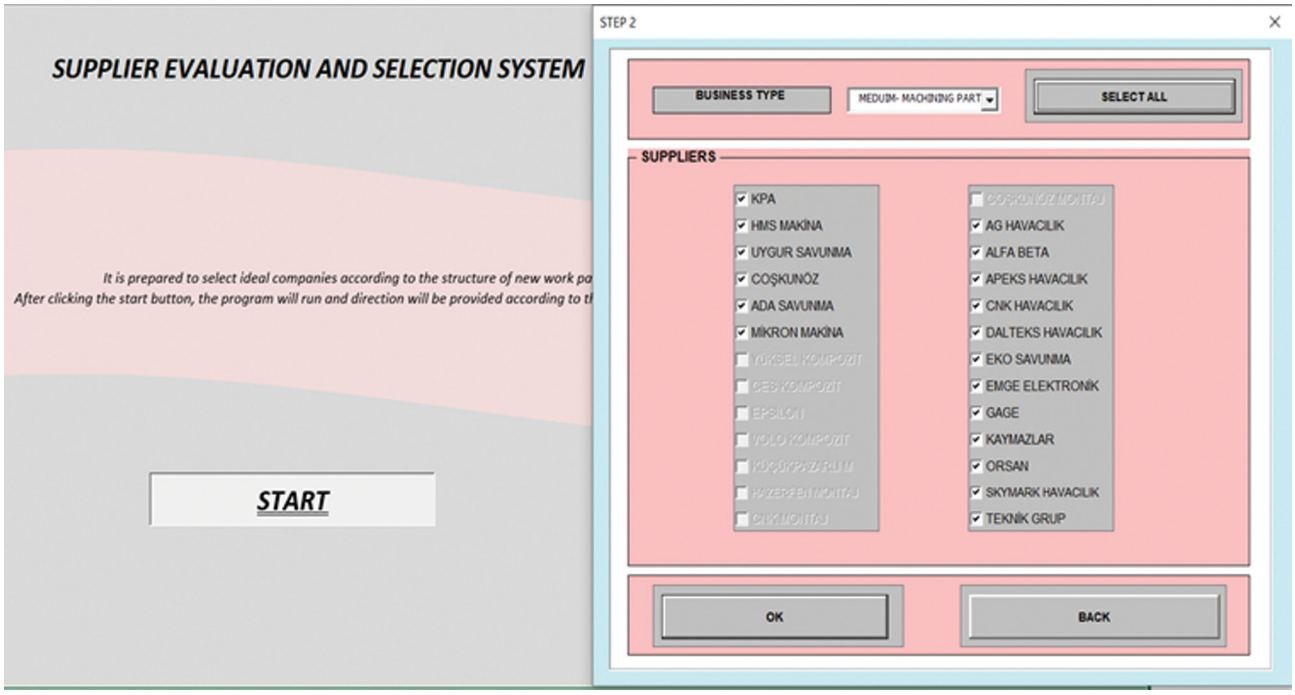

Figure 3. Software for Supplier Evaluation and Selection.

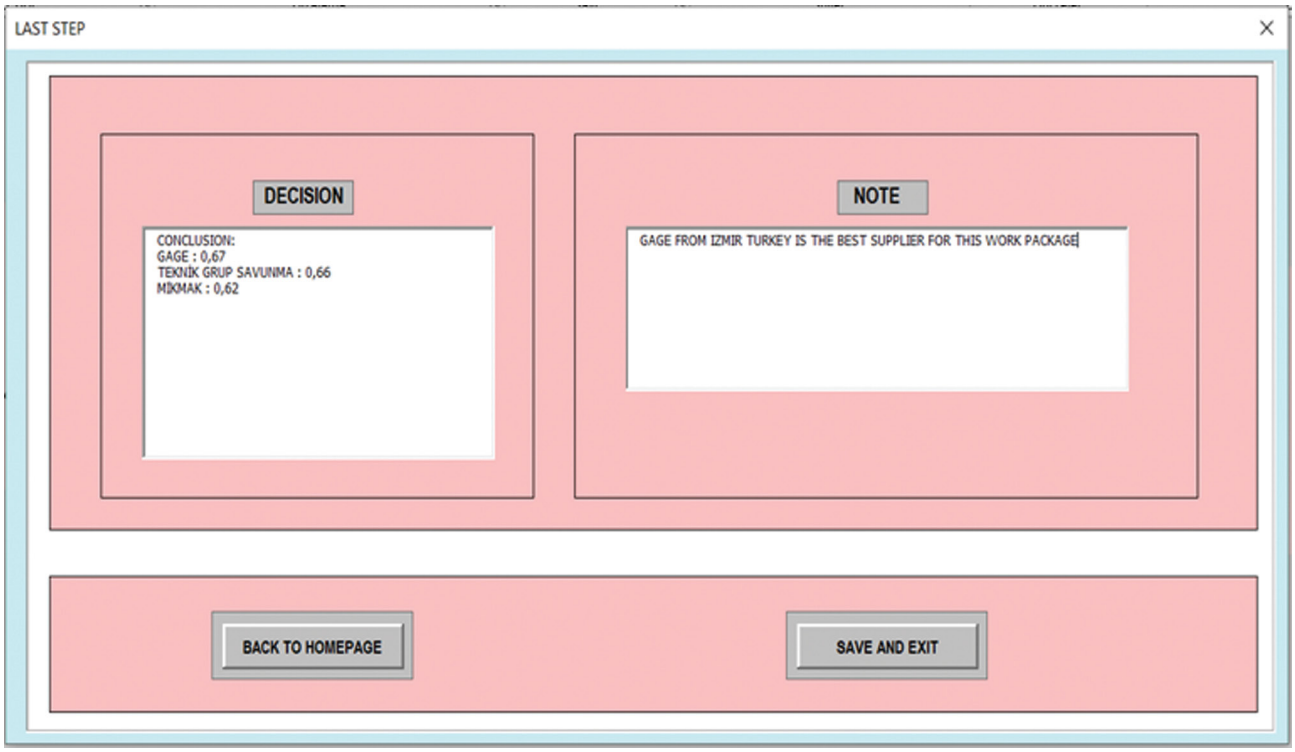

Figure 4. Decision Page of the Software.

supplier selection and operational management tasks. As a result of meetings and brainstorming processes organized to get the opinions of the team, 6 criteria and 18 sub-criteria were determined (Figure 5).

The criteria and sub-criteria aforementioned in Figure 5 are given below with their meanings;

Strategy: Represents the compliance of the suppliers to the customer vision and growth target. The strategy criterion consists of two sub criteria. Strategic Alignment: It represents the vendor's ability to adapt strategically to customer vision and growth targets. Investment Potential: It represents the supplier firm's ability to invest in line with customer goals.

Performance: Represents the success of the supplier firm in the fields of quality, delivery and communication. The performance criterion consists of three sub criteria. Delivery Performance: it represents the company's performance in the delivery area. Quality Performance: it represents the performance of the company in the field of quality. Communication: It represents the performance of the supplier company in the field of communication.

Cost: Represents the cost impact of the supplier's action at the customer firm. The cost criterion consists of three sub criteria. Pricing: Represents the price policy according to the customer expectations in financial terms in proposals that are submitted to the company. Cost of Performance: Represents the performance impact of the supplier firm to the cost effect it creates on the customer. Logistics: Represents the evaluation of the company's logistics processes in terms of cost and time.

Institutionalism: Represents the performance of the supplier company in terms of corporate identity and human resources. The cost criterion consists of three sub criteria. Corporate Memory: The institutional history and experience of the supplier company to use for future as a learned lesson. Human Resources: Represents the employment quality of the supplier firm in accordance with the customer vision and goals. Customer Portfolio: Represents the analysis of the suppliers in its customer portfolio.

Development: Represents the performance of the supplier to adapt to the customer systems and targets. The development criterion consists of four sub criteria. Adaption to Systems: Represents the company's performance in adapting to customer systems. Education: Represents the education and training conditions given to the employee of the supplier in order to adapt to the customer needs. Innovation: Represents self-perpetuation performance of the supplier company in order to adapt to customer needs. Flexibility: Represents the flexibility of the supplier in terms of scheduling and working conditions likewise working hour, adding new shifts and etc. in order to adapt to customer needs.

Availability to Work: Represents the performance of the supplier company in compliance with the technical and financial requirements of the customer. The

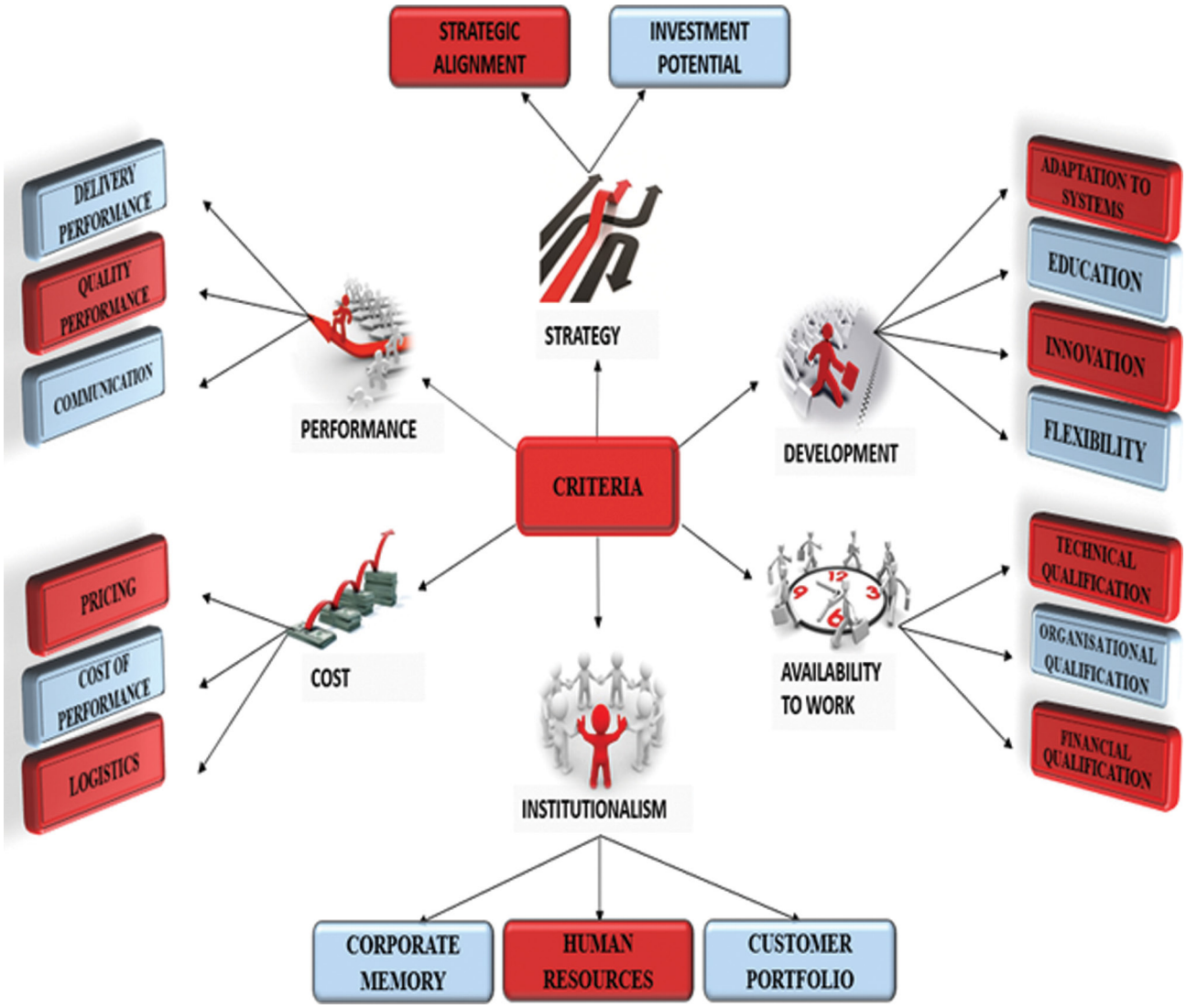

Figure 5. Criteria and Sub-Criteria.

availability to work criterion consists of three sub-criteria. Technical Qualification: Represents the technical competence of the supplier in order to meet the customer's needs. Organizational Qualification: Supplier company should have a strong organizational structure in order to meet customer needs. Financial Qualification: Financial profile of the supplier company should be good for long term relations.

For our study, a hierarchy tree was created using the criteria and sub-criteria given in Figure 5. Once the criteria were determined, it was asked to compare and score these criteria with a survey study submitted to the Contract, Production Planning, Quality and Manufacturing Engineering employee working in the company where the application was made. After that, in order to find the criteria and sub-criteria weights determined for the six business types, the AHP method was implemented.

CALCULATION OF CRITERION WEIGHTS

Our aim in this study with AHP method is the calculation of criterion weights to be used as a metric in TOPSIS method by performing the mathematical operations of AHP method in line with the six business types selected for supplier selection and application and the criteria and sub-criteria determined. Six different types of business selected for the study are the branches where the company is used most actively in its supply chain. These branches are technically evaluated and classified as easy machining parts, medium difficulty machining parts, hard machining parts, composite parts, easy assembly parts and hard assembly parts. In order to create comparison matrices for the AHP method, a questionnaire study was carried out. The survey, which consists of 6 pages, includes comparison matrices by business types and distributed as hard

copy, was filled out by the supply chain engineers mentioned in section 4.1. As result of the survey study the final values found by taking the geometric mean of the filled values.

After the survey results were obtained, the AHP method steps were followed and mathematical calculations were made for the medium difficulty machining parts, and the criteria and sub-criteria weights given in Table 2 were calculated.

When the criterion weights given in Table 2 are examined, the most important sub criterion for medium difficulty machining parts is "PRICING". The criterion of "DELIVERY PERFORMANCE" and "QUALITY PERFORMANCE" have equal weights and their importance degrees are very close to the pricing criterion. It means these three are dominant criterion for supplier selection. For the purpose of the study, the sub-criteria weights given in Table 2 were actively used in the solution of the TOPSIS method.

RANKING SUPPLIERS BY TOPSIS METHOD

In this study, TOPSIS method was used for providing a decision model and a support to decision makers during the decision for supplier selection. Eighteen sub-criteria described in section 4.1 were used for the TOPSIS method to reach the result. In order to determine the evaluation points using for the TOPSIS decision matrix, opinions and experience of 3 managers (1 Mechanical Engineer, 2 Industrial Engineer) working in supply chain department of the company where the study was conducted were taken and also for some of the criteria likewise performance criteria, data of the last six months were taken from the company database. The TOPSIS method for the study was carried out in six steps, these steps are; forming a decision matrix, standardization (normalization) of the decision matrix, creation of a weighted normalized decision matrix (in this process, criterion weights determined by AHP method were used.), finding ideal (A^+) and negative ideal (A^-) solutions, calculating the distances between alternatives, calculation of the relative proximity to the ideal solution and as a result, the ranking of companies.

Following the steps of the TOPSIS method, mathematical calculations were performed for the medium difficulty machining parts and the relative proximity to the ideal solution values given in the Table 3 were calculated.

The study was conducted with 26 different suppliers but 18 of them are capable for producing machining parts, the other eight are capable for just composite and assembly parts that's why the calculation was made for 18 suppliers. The relative proximity values for them in the medium difficulty machining parts business type were calculated. When the results are analyzed, company 22 is in the first place with the value of 0.67, company 26 is the second with the value of 0.66, and company 6 is at the third place with the value of 0.62. In summary, 22 is the most ideal company for the selected business type in today's conditions.

Table 2. AHP Method Criteria Weight Results

CRITERIA	CRITERIA WEIGHTS	SUB-CRITERIA	SUB-CRITERIA WEIGHTS
STRATEGY	0.08	STRATEGIC ALIGNMENT	0.056
		INVESTMENT POTENTIAL	0.019
PERFORMANCE	0.32	DELIVERY PERFORMANCE	0.129
		QUALITY PERFORMANCE	0.129
		COMMUNICATION	0.064
COST	0.25	PRICING	0.147
		COST OF PERFORMANCE	0.049
		LOGISTICS	0.049
INSTITUTIONALISM	0.08	CORPORATE MEMORY	0.050
		HUMAN RESOURCES	0.021
		CUSTOMER PORTFOLIO	0.008
DEVELOPMENT	0.11	FLEXIBILITY	0.044
		ADAPTATION TO SYSTEMS	0.036
		EDUCATION	0.016
		INNOVATION	0.016
AVAILABILITY TO WORK	0.17	TECHNICAL QUALIFICATION	0.067
		ORGANISATIONAL QUALIFICATION	0.067
		FINANCIAL QUALIFICATION	0.034

Table 3. TOPSIS Method Relative Proximity Values

SUPPLIERS	$C\dot{I}^{+}$	RANKING
COMPANY 1	0.54	6
COMPANY 2	0.42	12
COMPANY 3	0.41	13
COMPANY 4	0.36	15
COMPANY 5	0.46	10
COMPANY 6	0.62	3
COMPANY 15	0.35	17
COMPANY 16	0.61	4
COMPANY 17	0.44	11
COMPANY 18	0.54	5
COMPANY 19	0.36	16
COMPANY 20	0.52	8
COMPANY 21	0.39	14
COMPANY 22	0.67	1
COMPANY 23	0.51	9
COMPANY 24	0.35	18
COMPANY 25	0.53	7
COMPANY 26	0.66	2

SUPPLIER SELECTION RESULTS FOR ALL BUSINESS TYPES

When the evaluation results for the six business types are analyzed with AHP method, for easy machining parts, "PRICING" criterion with a 0.24 weight rating has emerged as the most important criterion, "DELIVERY PERFORMANCE" and "QUALITY PERFORMANCE" criteria follow pricing with 0.10 weight ratings as the same as medium difficulty machine parts but pricing criterion is more dominant on this business type. For medium-difficulty machining parts, "PRICING" criterion is again at the first place, with a weight of 0.14, but the criterion is not as dominant as it was for easy machining parts. "PRICING" criterion for medium-difficulty machined parts is followed by "DELIVERY PERFORMANCE" and "QUALITY PERFORMANCE" with 0.13 weight ratings. "PRICING" for hard machining parts is in the tenth place with a weight of 0.05, "DELIVERY PERFORMANCE" and "QUALITY PERFORMANCE" in this branch are the first with a weight of 0.18, followed by the "COST OF PERFORMANCE" with a weight of 0.1. The most important criterion for composite parts is "TECHNICAL QUALIFICATION" with a weight of 0.15, followed by "PRICING" and "COST OF

Table 4. The Criteria Weights for Six Business Types

BUSINESS TYPE/CRITERIA	EASY-MACHINING PARTS	MEDUIM DIFFICULTY-MACHINING PARTS	HARD-MACHINING PARTS	COMPOSITE	EASY- ASSEMBLY	HARD-ASSEMBLY
STRATEGIC ALIGNMENT	0.051	0.056	0.063	0.035	0.107	0.142
INVESTMENT POTENTIAL	0.017	0.019	0.021	0.035	0.035	0.047
DELIVERY PERFORMANCE	0.106	0.129	0.181	0.113	0.152	0.131
QUALITY PERFORMANCE	0.106	0.129	0.181	0.113	0.084	0.131
COMMUNICATION	0.035	0.064	0.060	0.023	0.046	0.044
PRICING	0.243	0.147	0.048	0.106	0.116	0.037
COST OF PERFORMANCE	0.100	0.049	0.095	0.106	0.074	0.038
LOGISTICS	0.040	0.049	0.048	0.035	0.092	0.013
CORPORATE MEMORY	0.030	0.050	0.057	0.044	0.025	0.056
HUMAN RESOURCES	0.019	0.020	0.019	0.018	0.016	0.023
CUSTOMER PORTFOLIO	0.008	0.008	0.019	0.007	0.020	0.009
ADAPTATION TO SYSTEMS	0.053	0.036	0.043	0.069	0.030	0.033
EDUCATION	0.017	0.016	0.009	0.021	0.015	0.046
INNOVATION	0.028	0.016	0.010	0.029	0.015	0.046
FLEXIBILITY	0.025	0.044	0.023	0.035	0.030	0.012
TECHNICAL QUALIFICATION	0.061	0.067	0.080	0.150	0.057	0.095
ORGANISATIONAL QUALIFICATION	0.033	0.067	0.015	0.030	0.057	0.047
FINANCIAL QUALIFICATION	0.018	0.033	0.028	0.030	0.029	0.047

PERFORMANCE" with a weight of 0.10. The most important criterion for easy assembly parts is the "DELIVERY PERFORMANCE" with a weight of 0.15, pricing is 0.12, and the "STRATEGIC ALIGNMENT" is the third important criterion with a weight of 0.10. "STRATEGIC ALIGNMENT" criterion with the weight of 0.14 is the first for hard assembly parts; the strategic alignment criterion is followed by, "DELIVERY PERFORMANCE" and "QUALITY PERFORMANCE" with 0.13 weight degrees. The weight results for all the criteria for all the business types are given at Table 4 in detail.

When the importance degrees at Table 4 are examined independently from the business types, pricing comes to the forefront for the parts with simple difficulty level while the difficulty level increases, performance, technical competence and strategy criteria come to the fore.

Twenty-six different companies were analyzed with the TOPSIS method and as a result of these analyzes, ranks were determined for the six business types, these results are given in detail in Table 5.

When the results at Table 5 are examined, larger and institutional companies become prominent as component structures, and business types become more complex and harder, on the other hand for basic jobs, smaller companies with cost advantages are recommended. As it could be seen at Table 5, some companies were highlighted with "–" and not ranked. This means that these companies were not operating in given business types.

SENSITIVITY ANALYSIS

After the ranking of the alternative suppliers for the selected business types was determined, sensitivity analysis was conducted to review the system variability. With the sensitivity analysis, the aim was to see how sensitive the results of our system were to the changes in the criteria

Table 5. Ranks for Companies at the Business Types

BUSINESS TYPE/ COMPANIES	EASY-MACHINING PARTS	MEDUIM DIFFICULTY-MACHINING PARTS	HARD-MACHINING PARTS	COMPOSITE	EASY-ASSEMBLY	HARD-ASSEMBLY
COMPANY 1	10	6	1	-	-	-
COMPANY 2	17	12	5	-	-	-
COMPANY 3	16	13	3	-	-	-
COMPANY 4	13	15	17	-	-	-
COMPANY 5	8	10	16	-	-	-
COMPANY 6	4	3	4	-	-	-
COMPANY 7	-	-	-	1	-	-
COMPANY 8	-	-	-	2	-	-
COMPANY 9	-	-	-	3	-	-
COMPANY 10	-	-	-	4	-	-
COMPANY 11	-	-	-	-	3	1
COMPANY 12	-	-	-	-	2	2
COMPANY 13	-	-	-	-	1	3
COMPANY 14	-	-	-	-	4	4
COMPANY 15	9	17	18	-	-	-
COMPANY 16	3	4	13	-	-	-
COMPANY 17	12	11	8	-	-	-
COMPANY 18	5	5	12	-	-	-
COMPANY 19	15	16	15	-	-	-
COMPANY 20	6	8	11	-	-	-
COMPANY 21	18	14	6	-	-	-
COMPANY 22	2	1	9	-	-	-
COMPANY 23	7	9	10	-	-	-
COMPANY 24	14	18	14	-	-	-
COMPANY 25	11	7	2	-	-	-
COMPANY 26	1	2	7	-	-	-

Table 6. Ranks of Companies Based on the Difference of the Criterion Pricing

ALTERNATIVE SUPPLIERS	-60%	-40%	-20%	CURRENT SITUATION	20%	40%	60%
COMPANY 1	1	1	4	6	8	9	10
COMPANY 2	3	7	10	12	13	13	16
COMPANY 3	5	9	12	13	14	16	17
COMPANY 4	14	15	15	15	16	14	13
COMPANY 5	16	14	13	10	10	8	8
COMPANY 6	4	4	3	3	4	4	4
COMPANY 15	18	18	18	17	12	11	9
COMPANY 16	13	8	6	4	3	3	3
COMPANY 17	10	12	11	11	11	12	12
COMPANY 18	8	6	7	5	5	5	5
COMPANY 19	15	16	16	16	17	15	14
COMPANY 20	11	10	8	8	6	6	6
COMPANY 21	9	13	14	14	15	18	18
COMPANY 22	6	3	1	1	1	1	1
COMPANY 23	12	11	9	9	7	7	7
COMPANY 24	17	17	17	18	18	17	15
COMPANY 25	2	2	5	7	9	10	11
COMPANY 26	7	5	2	2	2	2	2

weights. Effects of changing the weight of the pricing criterion, which is the most dominant one for medium difficulty machining parts, was analyzed at the study. As a result, not only the weight changes of the criterion were shown, but also how the differences in the weight of this criterion differentiated ranking of the supplier.

In the first stage of the sensitivity analysis, the changes in the pricing sub-criterion by plus and minus 20, 40 and 60 percent were calculated. In the second stage, TOPSIS method was applied for seven different situations, and changes in company rankings were analyzed. Company rankings are given according to the calculations in Table 6.

When the results of sensitivity analysis in Table 6 are analyzed, it is observed that the three companies that are most affected by the "PRICING" criterion are company 1, company 25 and company 2 while the mentioned companies will be the most preferred three companies if the pricing criterion is reduced by 60 percent, in normal conditions they are 6th, 7th and 12th companies, respectively. On the other hand, considering the company 22, company 26 and company 6, which are the most preferred companies in the current situation, with the effect of decreasing in weight of pricing criterion, these companies' effectiveness disappears. The analysis shows that these three companies are low cost companies with lower technical capability. Detailed analysis for eighteen companies which are operating in the machining business type is given in Figure 6.

As shown in Figure 6, importance changes at the criterion pricing have a sensitive structure for supplier evaluation and selection process.

CONCLUSIONS AND RECOMMENDATIONS

Companies need to have a dynamic and sustainable structure, plans and strategies in order to adapt to the difficult business conditions in today's global economic conditions. Agility and flexibility are the most important concepts in achieving this adaptation. In order to have an agile and flexible structure, companies need a very strong supply chain management organization. There are two main objectives in supply chain management, these are price and quality. Competition in price and quality is no longer just about effective facility and production management, besides, efficient use of scarce resources and finding the ideal and cost-effective suppliers in terms of raw materials and production have become an important issue of supply chain management, and also other important point is to manage these suppliers based on efficiency. Due to all these requirements, choosing the right supplier is one of the most important processes to be successful in supply chain management and to be one step ahead of competitors. In supplier evaluation and selection processes, companies try to find the conditions that will create a profit for both them and the supplier firm that serves their own goals and customer demands. Although the process of finding the right supplier seems

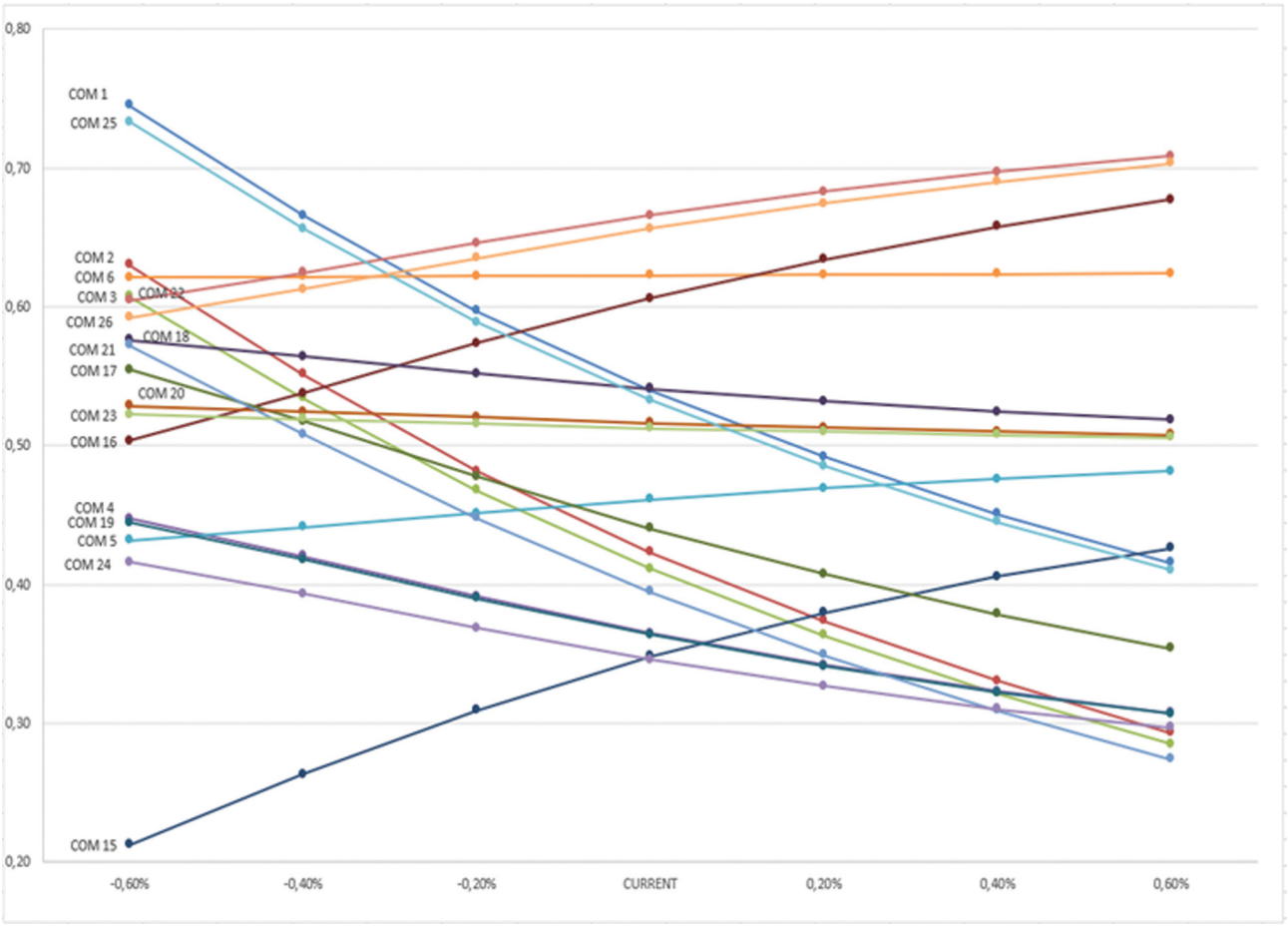

Figure 6. Sensitivity Analysis for companies.

easy at first glance, it appears to be a complicated problem that needs to be solved by supply chain professionals.

In this study, a structure was developed in order to support the solution of supplier evaluation and selection problems of the company by using the MCDM methods. The company operating at defense industry sector, already have more than one hundred domestic and international active suppliers, and besides that the company has been constantly developing, that's why more suppliers will be needed for new projects in the future. When analyzes were made to meet this need, the study was carried out by dealing with twenty-six suppliers involved in business types of easy, medium difficulty, and hard machining parts, composite parts production, easy and hard assembly parts, which were almost %96 percent of all the outsourcing activities of the company. In line with the literature researches and expert opinions examined for the study, it was preferred to apply AHP and TOPSIS methods, which are among MCDM methods. Finally, the software was written with VBA programming language in excel, which included the mentioned methods, it was aimed that decision makers could quickly reach the effective solution with up-to-date data. The methods used in this study were applied to specific circumstances to the company operating at defense industry sector in Turkey, and also it took special industry needs into consideration when analyzing alternatives. These are the main differences from the other studies in literature.

In the implementation steps of the study, primarily supplier evaluation and selection criteria were determined by using expert opinions. These criteria consisted of six criteria and eighteen sub-criteria. The main six criteria were strategy, performance, cost, institutionalism, development and availability to work. With using these six criteria and eighteen sub-criteria, a hierarchical structure was created. In order to resolve the hierarchical structure and to calculate criteria weights, comparison matrices were filled with a survey study applied to twenty engineers who were experts in their fields, and with mathematical calculations of AHP method, weight values of the criteria were reached. TOPSIS method was applied by using the evaluation criteria weights obtained by using AHP method to make the most effective selection among the alternative suppliers. By using TOPSIS method, relative proximity values for finding the ideal solution for twenty-six suppliers were calculated. All these methods were coded with VBA programing language in excel and presented as a software for the use of decision makers.

Excel based supplier evaluation and selection software written with VBA programming language can be used in new work packages and accurate results can be obtained, provided that data is regularly updated according to changing conditions, and it is recommended to use the software for the personnel working for supply chain professionals of the enterprise where the application is carried out. With this software, it is aimed to evaluate supplier evaluation and selection process in a systematic framework, which can be comprehensible, agile and cost-free. In addition, the method and software presented are more than just meeting the needs of the company where the application is carried out, it can be applied to many different companies and sectors.

With the use of the developed software in supplier evaluation and selection processes, it is aimed to provide support to supplier management specialists of the company in process efficiency, agility and accuracy. When the opinions of the specialists and their managers working in supply chain management departments, which are active users of the software, are received; it has been emphasized that the proposed method has valuable contributions to the targeted subjects, and in addition to this, some points that are open to human error due to the large number of suppliers and criteria are reduced by this software.

Limitations to be considered when examining the results of the study; experts are experienced to provide the correct information, the study is based on existing data, when the importance of the criteria and the performances of the companies change, the decision support system should be rerun as the software was created for adapting to these dynamic conditions.

Researchers who will perform similar studies can update the data used in the proposed methods according to their study conditions and use them as a solution method for different businesses or sectors. Also, researchers can use different MCDM methods or fuzzy versions of AHP and TOPSIS methods. This study was performed at defense industry sector in Turkey. Criteria and criteria weights should be determined with different types of data for different studies and sectors. In our study, Excel based software developed with VBA code was used. This software can be developed with different programming languages or different perspectives. By establishing online systems for companies with facilities in more than one region, more effective results can be achieved with the participation from different departments and regions.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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